

Zooplankton Aggregations Near Sills

Mark V. Trevorrow
Defence Research and Development Canada - Atlantic,
PO Box 1012, Dartmouth, Nova Scotia, B2Y 3Z7 Canada
phone: (902) 426-3100 x 315 fax: (902) 426-9654 email: Mark.Trevorrow@drdc-rddc.gc.ca

Award Number: N00014-01-1-0273

LONG-TERM GOALS

This project seeks to understand the biological and physical mechanisms for producing and maintaining dense aggregations of zooplankton in regions where ocean currents interact with steeply-sloping coastal sills.

OBJECTIVES

The primary goal during FY01/02 was to quantitatively assess zooplankton distributions and species in Knight Inlet, with special focus on the sill near Hoeya Head. This area has been the subject of considerable ONR-sponsored oceanographic research in the past focused on the stratified flow features induced by the sill (e.g. Farmer and Armi 1999; Klymak and Gregg 2001). Echo-sounder surveys performed in 1995 (reviewed during last FY) showed interesting zooplankton aggregations in this area, however the earlier acoustic systems were not calibrated nor were any zooplankton samples acquired.

APPROACH

This work combined expertise in multi-frequency acoustics, conventional zooplankton trawls, and in situ optical techniques in a two-week field survey of Knight Inlet. Repeat transects across the sill with a vessel-based, three-frequency echo-sounder system were supplemented with multi-net (BIONESS) trawls and bongo nets (operated by D. Mackas and group of IOS), profiles with a new high-resolution camera system (ZOOVIS, operated by M. Benfield of LSU), and optical plankton counter casts (operated by R. Campbell and T. Ross, graduate students at the Univ. of Victoria). Additional broad-area acoustic and in situ surveys covering the entire length of Knight Inlet were conducted. Acoustic Doppler current-meter and inverted echo-sounder moorings were deployed just west of the sill, and CTD casts throughout the entire inlet were conducted.

WORK COMPLETED

A two-week field survey on board the *CCGS Vector* was conducted in Knight Inlet Nov. 12 to 25, 2001. A three-frequency (40, 100, and 200 kHz), narrow-beam echo-sounder system was built and tested by the IOS Acoustical Oceanography group, and then operated by the author during the field trials. This system was utilized for transects across the sill and wide-area surveys in other areas of the inlet, and for comparison with zooplankton net casts and profiles with in situ optical devices. Echo-sounder transects were conducted across the sill during both ebb- and flood-tide conditions and during day- and night-time. The echo-sounders recorded data up to 200 m depth with pulse lengths near 50 cm and ping-rates near 1 Hz.

The three-frequency echo-sounder system was acoustically calibrated using the backscatter from several sizes of metal target spheres. These calibrations included detailed measurement of the systemic time-varying gains and noise levels. This allows volumetric backscatter cross-section profiles to be generated, which then allows discrimination between different scattering layers on the basis of frequency-dependence and quantitative estimates of zooplankton abundance. Recent, ongoing work has focused on quantitative comparisons between the acoustic scattering and abundance-species information from the BIONESS trawls and profiles with ZOOVIS and the Optical Plankton Counter.

Additionally, a mooring comprised of two (44 and 307 kHz) self-contained, inverted echo-sounders (IES) was deployed at 90 m depth just west of the sill at Hoeya Head. These IES units recorded 5-s ensembles continuously throughout the field trials, thus monitoring the temporal changes (dominantly the nocturnal migration) in the zooplankton and fish abundance.

RESULTS

The high-resolution vessel-based echo-sounders produced dramatic images of the complex internal hydraulic flows and resulting zooplankton and fish distributions in the vicinity of the sill. Figure 1 shows a good example from a combined echo-sounder and BIONESS trawl over the sill during the day-time at mid-ebb tide. The total horizontal distance covered in this image is roughly 5 km. During the BIONESS trawl operations the echo-sounder display was used to guide the nets to particular scattering layers and features. In post-analysis the echo-sounder data provides a synoptic overview of the spatial context of the various net samples.

During the day zooplankton layers were generally observed deeper than 65 m depth, with only faint flow lines (presumably) due to microstructure scattering in the upper water column. In this example the flow lines extending downwards from 10 to 20 m depth illuminate an internal hydraulic flow separation, which has been the subject of earlier oceanographic studies (e.g. Farmer and Armi 1999; Klymak and Gregg 2001). One important result from this net trawl was the low abundance of zooplankton in the upper 50 m, and in particular the lack of zooplankton in the flow layers near 20 m depth. This strengthens the hypothesis that the flow lines seen on the echo-sounder are due to microstructure scattering, however no turbulence measurements were made. The peak back-scattering strength of these flow lines was found to be roughly -75 dB (re 1 m^{-1}). Within the deeper zooplankton layers, Figure 1 shows two distinct scattering regions: a less intense but relatively smooth-textured zone from 65 to 100 m depth, and a stronger but more granular scattering region below 100 m. The 65 to 100 m region was seen only on the 100 and 200 kHz sounders and not with the 40 kHz, whereas the deeper layer showed similar scattering levels in the 40 and 100 kHz sounders (the 200 kHz was noise-dominated below 100 m). This separation of scattering layers was commonly observed in all areas of Knight Inlet during these surveys. The difference in scattering *texture* between the two zones suggests that scattering statistics and critical density analyses (similar to those reported by Trevorrow and Tanaka 1997) might prove useful.

Also shown in Fig. 1 are two fish schools roughly 10 m high on the sill crest. These schools are believed to be juvenile fish because of their frequency-independent scattering signature and volumetric backscatter strength near -50 dB (re 1 m^{-1}). Such schools were commonly observed on the sill crest, however their species and sizes are unknown as they were not caught with the zooplankton nets.

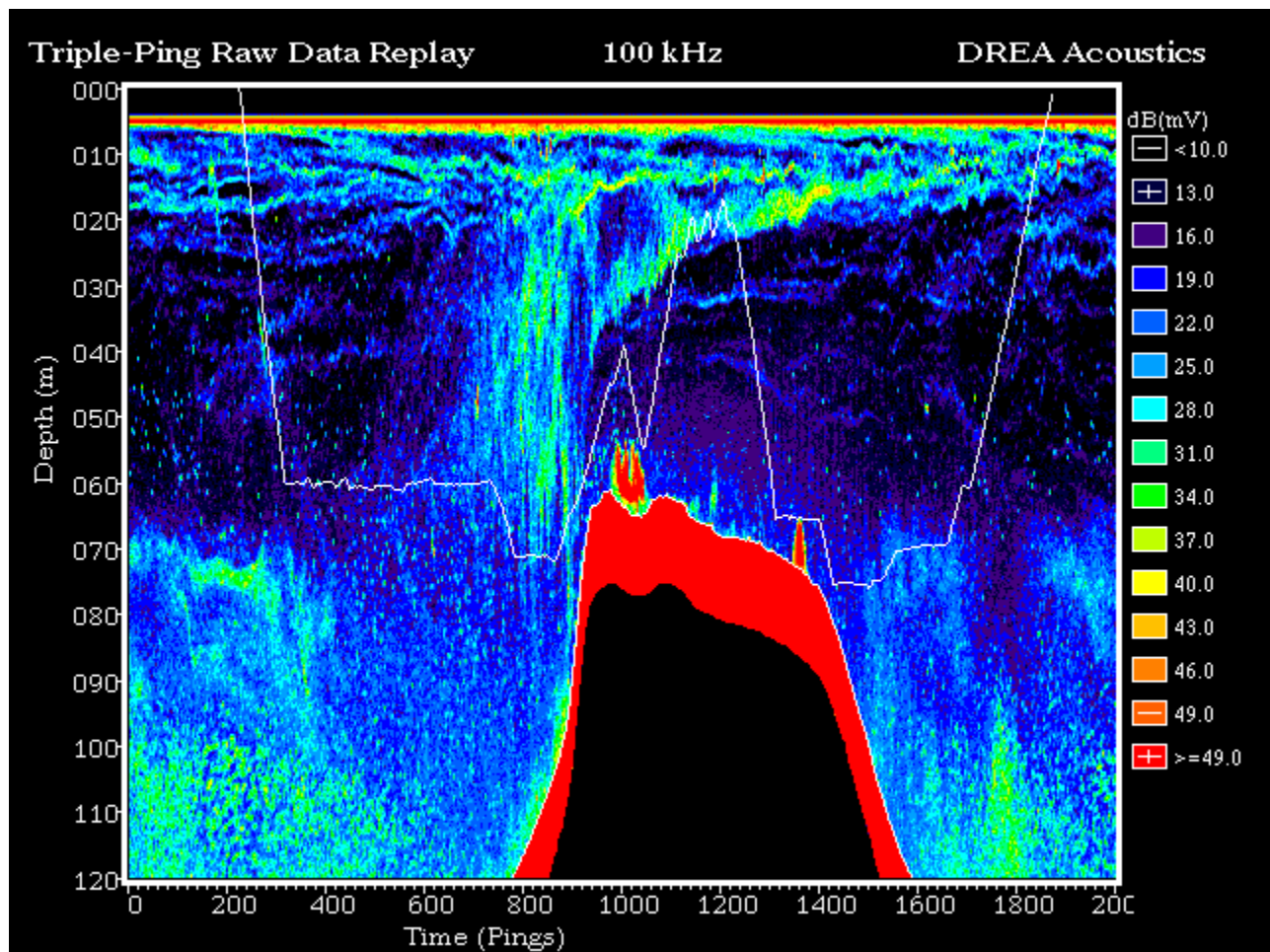


Figure 1: Raw intensity vs. depth and time from vessel-mounted 100 kHz echo-sounder during east-bound transect over the Knight Inlet sill, starting 1116h Nov. 22, 2001. Time in pings at 1.5 s per ping (total of 50 minutes). Raw intensity has been normalized to $20\log[\text{range}]$ variation. Transect was taken during mid-ebb tide, with flow right to left. Near-surface layers show flow bifurcation over the western side of the sill. White line shows path of BIONESS plankton net.

The acoustic calibrations allow important cross-frequency comparisons to be made, as shown for example in Figure 2. These profiles were taken in the Glacier Bay region of upper Knight Inlet, well away from the stratified flow disturbances of the sill. This location showed little spatial variations in scattering layers, and thus served as an excellent location for comparing different zooplankton sampling techniques. The figure clearly shows the separation of the day-time scattering layer into two regions (similar to Figure 1): one from 62 to 93 m depth which shows scattering strength increasing with frequency, and the other from 93 to 150 m depth which shows frequency-independent (geometric) scattering. The upper layer scattering signature is consistent with back-scatter from crustacean zooplankton such as Euphausiids, Amphipods, and large Copepods. At these frequencies, crustaceans of this size lie at the transition between Rayleigh and geometric scattering. BIONESS tows in this layer showed higher Euphausiids densities (up to 3 per m^3) with sizes in the range 10 to 17 mm, with elevated numbers of amphipods (5 to 15 mm length) and larger copepods. A cast with the ZOOVIS camera through this layer observed 8 mm Euphausiids with abundance up to 50 per m^3 . Using approximate target strengths for 10 mm crustaceans of -80 dB and -75 dB (re 1 m^2) at 100 and 200

kHz respectively (see Trevorrow and Tanaka 1997), the peak scattering strengths shown in Fig. 2 correspond to densities near 20 per m^3 . Given the vastly different sampling volumes of the acoustics, nets, and in situ cameras this agreement is remarkable, although more work on such comparisons is necessary. Specifically, size distributions of Euphausiids, Amphipods, and Copepods from the BIONESS trawls and OPC casts can be used to test the validity of zooplankton scattering models.

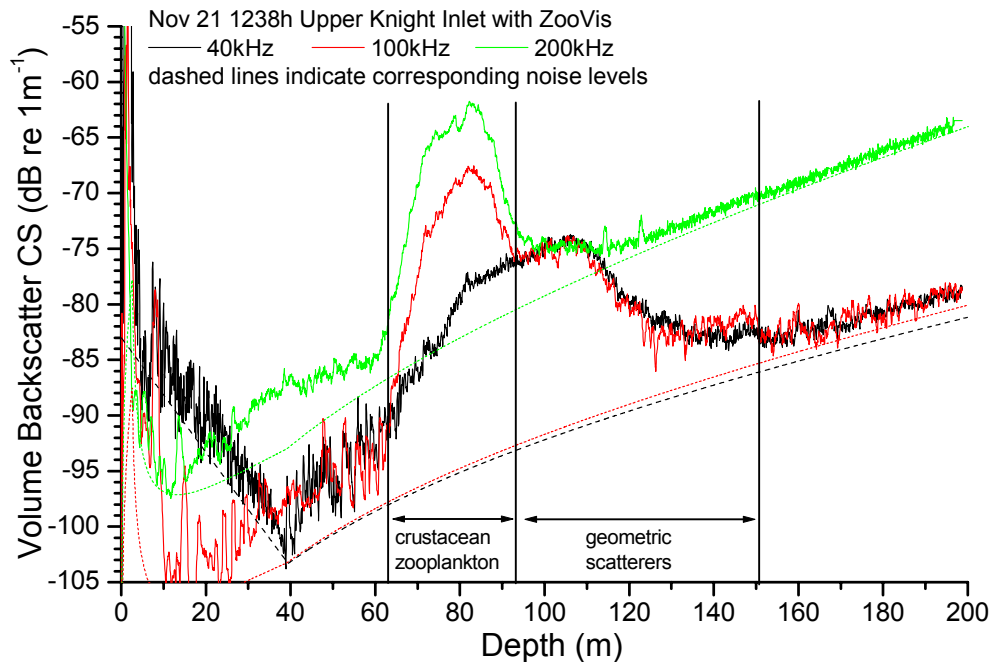


Figure 2: Comparison of volumetric backscatter cross-section profiles at three frequencies (40, 100, and 200 kHz), collected in Upper Knight Inlet at 1238h, Nov. 21st, 2002. Profiles were acquired at the same time as deployment of ZOOVIS device, and show a crustacean scattering layer from 62 to 93 m depth, with a deeper layer (93 to 150 m) exhibiting geometric scattering. Dashed lines show corresponding systemic noise levels.

The species composition of the deeper *geometric* scattering layer is still unresolved. Crustacean scattering can be ruled out because the abundances in this layer are an order of magnitude lower than in the upper layer and the frequency dependence is incorrect. One interesting result from the BIONESS trawls is a larger concentration of Bracts (from siphonophores) at these depths, suggesting that the scattering is due to pneumatophores (gas-filled floats at the top of the siphonophore colony). This hypothesis will be more carefully examined. However, without net samples capable of catching juvenile fish, the competing hypothesis of fish scattering cannot be dismissed.

IMPACT/APPLICATIONS

It is hoped that this work and subsequent field-trials will provide a better understanding of:

1. the links between zooplankton spatial aggregations, predator species (such as planktivorous fish), and physical oceanographic phenomena.
2. the efficacy of combining multi-frequency acoustic with in situ plankton sampling techniques such as nets trawls and optical systems.

3. the validity of various existing acoustic scattering models of zooplankton in the context of multi-species and multi-sized zooplankton populations.

TRANSITIONS

The results from this work will be used by the author and other collaborators to improve zooplankton and fish sampling techniques for the fall 2002 field trials. For example, trawl nets capable of sampling the juvenile fish schools observed on the sill crest will be deployed, and a new multi-beam sonar capable of mapping the fish school distributions will be tested.

RELATED PROJECTS

This project is coupled with projects headed by D. Mackas from IOS and M. Benfield from Louisiana State Univ., with the common aim of understanding zooplankton aggregations at the Knight Inlet sill. D. Mackas is responsible for coordination of ship-time on the CCGS Vector, and along with his group at IOS for operation of an instrumented BIONESS trawl and subsequent processing of the zooplankton samples. Additionally, D. Mackas is working to develop and maintain a multi-frequency echo-sounder capability for his ecology group at IOS. M. Benfield is developing and testing an in situ optical zooplankton imaging system (ZOOVIS).

REFERENCES

Farmer, D., and L. Armi, 1999. Stratified flow over topography: the role of small-scale entrainment and mixing in flow establishment, *Proc. Roy. Soc. London* **A455**: 3221-3258.

Klymak, J., and M. Gregg, 2001. Three-dimensional nature of flow near a sill, *J. Geophys. Res.* **106**(C10), 22295-22311.

Trevorrow, M., and Y. Tanaka, 1997. Acoustic and in-situ measurements of freshwater amphipods (*Jesogammarus annandalei*) in Lake Biwa, Japan, *Limnol. Oceanogr.* **42**(1), 121-132.

PUBLICATIONS

Trevorrow, M., 2001. *Zooplankton aggregations near a coastal sill: an examination of echo-sounder data from August and September 1995 in Knight Inlet*, B.C. DREA Technical Memorandum 2001-119, Defence Research Establishment Atlantic, Dartmouth, NS, 35 pages.